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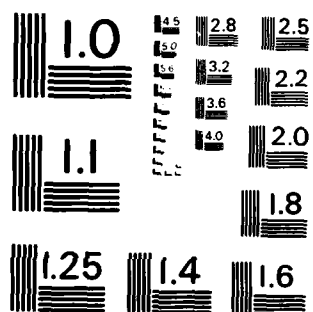
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Current research is summarized for the parameter identification of a class of polynomial differential systems via the modulating function method. The underlying computations involve calculating a finite number of Fourier coefficients of the input-output data which can be determined using a fast Fourier transform algorithm. Current research is also described for devising stabilizing feedback control laws for a class of differential-delay systems using a spectral factorization of the state space.

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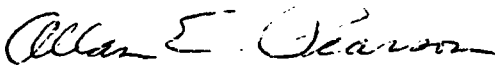
CONTROL AND IDENTIFICATION OF TIME VARYING SYSTEMS

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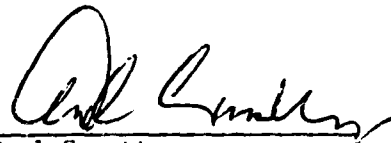
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I. Summary of Progress and Continuing Research

The over-all objective in this research program is to develop a step-by-step identification-control strategy for time varying dynamical systems which utilizes input-output data in block data form over short time intervals. Hence, the identification portion of this objective is to obtain computationally feasible algorithms for parameter identification which can work with time limited data. The publications and papers listed in Section II, Ref. (1)-(5), are concerned in one way or another with this objective.

The parameter identification of a class of nonlinear differential systems is developed in (1) and (2) using a modulating function technique originally due to Shinbrot.¹ This development follows the application of the modulating function method presented in Pearson and Lee² for linear differential systems. Here it is shown how a set of commensurable sinusoids can be used in forming a modulating function vector such that the underlying computations for a least squares estimate of the system coefficients involve calculating a finite set of Fourier coefficients of the time limited input-output data. In turn, these Fourier coefficients can be calculated very efficiently using a Fast Fourier Transform algorithm. In the case of the nonlinear differential system models considered in (1) and (2), the underlying computations involve determining the finite Fourier coefficients of powers and cross products of the time limited input-output data. If the input data consists of a linear combination of commensurable sinusoids over the finite time interval, the additional computations for the class of bilinear system models considered in (2) is shown to be essentially trivial over that which pertains to a linear system of the same order. This is a direct result of the interaction of the sinusoidal input and the trigonometric modulating functions. Current research in this area involves developing a maximum likelihood method for estimating the system coefficients in the presence of random noise

¹Shinbrot, N., "On the Analysis of Linear and Nonlinear Systems," Trans. of the ASME, pp. 547-552, April 1957.

²Pearson, A. E. and Lee, F. C., "Time Limited Identification of Continuous Systems using Trigonometric Modulating Functions," Proc. of Third Yale Workshop on Applications of Adaptive Systems Theory, pp. 168-173, New Haven, CT, June 1983.

which corrupts the Fourier coefficients of the input-output data. Also of interest to us is the system identification when sensor or filter dynamics affect the input-output data. This is a problem which has received very little attention in the system identification literature, but is certainly present in a practical situation.

The above described modulating function technique converts a differential equation in the input-output data to an algebraic equation involving functionals on the data unencumbered by the unknown initial (boundary) conditions. As such, it can be interpreted as a projection of the infinite dimensional data down into a finite dimensional vector of Fourier coefficients followed by another finite dimensional projection into a subspace which obviates dealing with all the unknown initial conditions. Viewed in this way, the modulating function method is a finite dimensional alternative to an infinite dimensional "annihilating" operator which was originally proposed in Pearson³ as a way to avoid dealing with unknown initial conditions when utilizing state variable filters on time limited data in system identification. The latter method was further developed in (3) to the identification of a class of differential-delay equation (DDE) models. There it is shown how the estimation of pure time delay can be decoupled from the estimation of the remaining system parameters via the use of the variable projection functional in nonlinear least squares theory. Obviating the necessity to deal with all unknown initial conditions is especially noteworthy here since the state of a DDE system is essentially infinite dimensional.

The results in (3) are adapted in (4) to the classic problem of estimating time delay in two received signals when the transmitting media are characterized by unknown transfer functions. Comparisons are also made with the Generalized Cross Correlation method with the conclusion that the simple cross correlation method works at least as well as the

³Pearson, A. E., "Finite Time Interval Linear System Identification Without Initial State Estimation," Automatica, Vol. 12, pp. 577-587, 1976

parameter estimation or phase data methods when the transmitting media possess zero memory. However, the cross correlation method breaks down, as would be expected, when the media possess dynamical (nonzero memory) characteristics. Simulation results are presented in (4) which illustrate the superiority of applying the results of (3) in this case, although the computational requirements are understandably much more demanding than the simple cross correlation method. Within this realm we hope to reduce the computational requirements significantly by adapting the modulating function approach to the time delay estimation problem. This represents an area for future investigation.

The paper published in (5) represents work in progress on the problem of estimating the target acceleration parameter in a two dimensional pursuit-evasion model when the range coordinate data is given over short time intervals. Although the original formulation and simulations were carried out using the annihilating operator approach, some additional simulations were run using the modulating function technique. The latter was noted to be superior, both with respect to accuracy of the estimated parameter and simplicity of implementation.

Another research area currently under investigation is that of devising stabilizing feedback control laws for DDE systems with delayed states. Our approach is to perform a spectral factorization of the state space into two parts: the acceptably stable portion, and that which corresponds to the unstable, or unacceptably stable, portion. Assuming there are fewer than " n " such unstable modes, where " n " is the order of the DDE model, we propose to design the feedback control using delay-free methods via a "reducing" transformation. This can be regarded as an extension of our earlier work on feedback control laws for DDE systems with delayed controls (Kwon and Pearson⁴).

Future work is planned on the extension of the modulating function method to the

⁴Kwon, W. H. and Pearson, A. E., "Feedback Stabilization of Linear Systems with Delayed Control", IEEE Trans. on Auto. Contr., AC-25, pp. 266-269, 1980.

identification of time varying systems and the investigation of alternative basis functions for constructing sets of modulating functions.

II. Publications and Papers In Press

- (1) Pearson, A. E. and Lee, F. C., "Parameter Identification for a Class of Polynomial Differential Systems", submitted to the IEEE for the 1984 CDC.
- (2) Pearson, A. E. and Lee, F. C., "Efficient Parameter Identification for a Class of Bilinear Differential Systems", submitted to the Seventh IFAC Symposium on Identification and System Parameter Estimation.
- (3) Pearson, A. E. and Wu, C. Y., "Decoupled Delay Estimation in the Identification of Differential Delay Systems", to appear in Automatica, late 1984.
- (4) Wu, C. Y. and Pearson, A. E., "On Time Delay Estimation Involving Received Signals", to appear in IEEE Trans. on Acoustics, Speech and Signal Processing, late 1984.
- (5) Pearson, A. E. and Luzzio, L. A., "Estimating Target Acceleration in Intercept Problems Using Modal Equation Errors", Proc. of the 22nd IEEE Conf. on Decis. and Contr., pp. 557-558, San Antonio, TX, Dec. 1983.

III. Supported Personnel

Y. A. Fiagbedzi	Research Assistant
F. C. Lee	Research Assistant
A. E. Pearson	Professor of Engineering and Principal Investigator

IV. Invited Seminars

January 30, 1984: General Motors Research Laboratories, "Continuous System Identification With Time Limited Data".

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